Rethinking Agriculture in a Warming Climate
Nina Fedoroff

DR. FEDOROFF: Thank you very much. It's a real pleasure to be here. We've been asked to be a bit provocative, and I hope to comply. But let me start with an even broader historical perspective than you've had so far. Worries about food, what we now call food security, are as old as mankind. It was perhaps Thomas Malthus who most clearly crystallized these concerns with the publication of his essay about 210 years ago. Curiously, and probably coincidentally, science began to enter agriculture in earnest at about the same time with Joseph Priestly's discovery that plants evolve oxygen.

Since that time, science has powered enormous gains in agricultural productivity through fertilizer production, mechanization, and plant breeding as well as chemical additives.

Critical to our current high productivity agriculture were the inventions of these two gentlemen, Haber and Bosch, who figured out how to fix nitrogen from the atmosphere where it's in unlimited supply and convert it to a form that plants can use. This is done now in huge plants around the world.

Another advance that Malthus couldn't have foreseen was the mechanization of agriculture, which has penetrated in many, many countries, but not everywhere. Yet long before science entered agriculture, people were genetically modifying plants to make them into suitable food crops. What you see here is the closest relative of our modern corn plant. It's called teosinte. It looks so different from our modern corn plant that it was originally assigned to a different species. And it wasn't until it was discovered that teosinte and corn could crossbreed that people began to appreciate how closely related they are. The outcome of crossing of these two plants yields everything from the teosinte rachis, which is at the top of the plant just as it is in other grasses, and small ears of corn.

Seeds of teosinte are hard as rock. Indeed, they have silica deposits at their surfaces. It was as long ago as 10 to maybe even 13,000 years ago that people gathered this collection of mutations—that's what genetic changes are called technically—together, and it turns out that it isn't a large number. It's only about half a dozen genetic changes that converted the seeds of a plant that was essentially not useful to people to one of our major food crops.

But it was in the 20th century that we saw the huge expansion of the ear. And that came from observations at the beginning of the century made at Cold Spring Harbor, and it's a little bit of an interesting story. It was George Harrison Shull who actually was asked to demonstrate the newly rediscovered Mendelian principles who inbred some strains of corn that he got from various places, and then he crossed them. And much to his surprise he suddenly got much bigger, sturdier plants with larger ears. He published a little paper that said, hmm, this might have a some bearing, some implications for agriculture.

Of course it took many more decades before hybrid corn was adopted, and indeed many of the things that people say about genetically modified crops today were said about hybrid corn then. Farmers didn't want to be compelled to buy seeds over and over again. They didn't want companies running their business, and so forth. But all that is history.

Of course we've done this with wheat. We've done it with rice. And we've done it with a huge variety of plants, principally increasing the sizes of fruits, making them less toxic, removing the seeds from them, making them healthier such as the Ruby Red grapefruit at the lower right, which was actually created by irradiating shoots of grapefruit at the Brookhaven National Lab and then sending them back to Texas to grow them out and examine for useful mutations.

Molecular biology entered agriculture roughly 30 years ago, and today of course we have the familiar modifications of a number of different crop plants—corn, cotton, with a gene from a bacterium Bacillus thuringiensis. It's often called the BT gene, but it is a toxin gene which is toxic to insects but not to people.

Today genetically modified crops, only a few of them actually, are grown on about 300 million acres in 25 different countries. There has been a lot of resistance to genetically modified crops in many countries, and I think that one of the things that we need to do today is to reexamine the regulatory process. We have a regulatory apparatus in this country that allows big biotech companies to get crops out to farmers. But I think one of the challenges for us going forward in creating a more sustainable agriculture is to reexamine those regulations in the light of accumulating evidence of the safety of GM crops.

The reason this is important is that over the past 30 years, most of my colleagues in plant sciences have turned away from working on crops. And that's because they can't afford the expense or time to go through the regulatory apparatus and get things out to farmers in the way that they have done over the history of our extension system and our land grant university system.

So I think that's one of the challenges. Not all crops will be developed by biotech companies, and we need to develop mechanisms that will allow our public sector scientists to get crops to farmers.

Now when Malthus was writing his essay, the population of the world was somewhere around a billion. By the middle of the 20th century, the population had tripled, and between the middle and the end it doubled again. We are now approaching seven billion. Amazingly enough, the population growth from 3 to 6 billion was accompanied by a reduction in the fraction of hungry people on the face of the earth from half to a sixth, because of the success of scientific agriculture.

Now the population experts are telling us that we need to anticipate the addition of some 3 billion more people to the population of the earth.

Here's a sobering factoid. The amount of arable land on the face of the earth hasn't changed appreciably, not much more than 10 percent, over the past half century, and it's not likely to increase in the future because we are losing it to desertification, urbanization, salinization as fast as we are adding it.

The food crisis of 2008 wasn't a crisis in the usual sense. It was a tipping point, perhaps a harbinger of things to come. We must also begin to think about the impact of climate change on agriculture. It's just beginning to be factored into our projections. The yellow line indicates the general temperature range over our major crop plants evolved. I draw your attention to the "x," which marks a historical temperature anomaly. That was the

summer of 2003, which was much hotter than the average over the last hundred years. If the climate projections are right, it will be an average summer a few decades from now, and by the end of the century it's going to be a cool summer. Let's look a little more closely at it.

These are temperature statistics from France showing deviations from the average for the past 100 years, and you can see the 2003 is an outlier. The average temperature was 3.5 degrees above normal, although rainfall was normal. We all heard about the 30,000 to 50,000 people that died, but what we didn't hear about was the 20 to 36 percent reduction in fruit and grain yields. That's what we can expect from that kind of temperature increase.

By the end of the century, it is projected that we will be experiencing summers warmer than the warmest now on record.

Yields of our major temperate crops decline rather markedly above about 30 degrees centigrade for several reasons. The temperature optimum for a photosynthesis is in the range of 20 to 25 degrees and its efficiency declines above that. In addition, development accelerates with temperature, so that there isn't as much time to convert the photosynthate into the oils and the starches that comprise the bulk of the harvested crop.

Another variable that is becoming critical is water. Today about 40 percent of the surface of the earth is dry lands, and some 35 percent of the population lives in drylands areas. Water tables in many of these dry regions are being drawn down more rapidly than they can be renewed. So we are approaching water crises, not only from increasing competing demands from energy production, urbanization, and others, but there will be additional drying and heating in some of the most populous places on the earth.

The red circles indicate the areas that are expected to experience moderate to severe water scarcity in the future. What that means is that the shape of the future is pretty daunting. Energy, freshwater and arable land are likely to be no more abundant, if anything less abundant. What will certainly increase is demand--that is the number of people—the extent of dry lands and the temperature.

So how do we go about adapting agriculture to climate change while we continue to increase productivity and decrease environmental impact? What people are talking about today is increasing tolerance to heat, drought and salinity. That's going on now in both biotech companies and in public breeding programs. Increasing pest resistance is important, because we're expecting and already seeing shifts in distribution of pests and diseases. But there are also big issues such as addressing the limits on photosynthetic efficiency, which is not a major research focus at the moment.

The kinds of techniques that are being used and will be used include conventional breeding and marker assisted breeding. In the future, however, it will require some combination of even more sophisticated marker assisted breeding and molecular modification. Here's where we are a bit stuck in the sense that although we have a regulatory apparatus, it is prohibitive. To encourage more active crop development, particularly in the public sector, the regulatory regime needs to be re-evaluated in the light of accumulated evidence on the safety of genetically modified crops.

I am growing increasingly convinced that we have to think well out of the box. We need to think about new crops, new methods, even new systems. And I'm going to just throw a few examples out. Desert agriculture and saline agriculture are at the moment not front and center in our agriculture, but there are institutions around the world that do research on both desert and saline agricultural systems. That is, growing crops that can tolerate high temperatures and salt. Several of the research centers are members of the CGIAR system, particularly ICRISAT and ICARDA, focus heavily on dryland agriculture.

The country that has focused most seriously on desert agriculture and been quite successful is Israel, investing in both research and on the production side.

Aquaculture has to be part of the answer. Here is some really startling numbers. A kilogram of fish can be raised with as little as 10 to 50 liters of water, depending of course on the source of the feed, and that water can be recycled. It takes in round numbers about a thousand liters of water to grow a kilogram of wheat, and around the world we feed almost half of our grain to animals. which use most of the grain to power their own existence. So if you look at the amount of water that it takes to raise a kilogram of hamburger, it's somewhere between 5 and 10 times as much as it takes to make a kilogram of grain.

Thus making better use of what will be most abundant—sunshine, saltwater, and desert—is extremely important. But there's another aspect at the heart of making agriculture more sustainable, and that's closing the nutrient loop between animals and plants. So for example, integrated aquaculture and agriculture systems have been developed on land, in the oceans and in fact in desert areas, using a variety of aquaculture combinations of aquaculture and agriculture, including halophyte agriculture.

I think we need to invest more in such closed systems because many of the problems that we have created with our modern high efficiency agriculture that have to do with the flow of nutrients that are not used by plants—that is, fertilizer and the fertilized contamination of water and the problems of recycling the wastes that are produced by animal agriculture.

In sum, I think that improving both the productivity and environmental sustainability of food production in a changing climate is among the most profound challenges facing face humanity in the 21st century. Thank you.

[Applause]

MODERATOR: We can take one or two quick questions.

REPORTER: In your historical review, let me ask this about the patenting of advances. Under FDR and Henry Wallace, in fact the fathers of Henry Wallace too and grandfather, it was very explicit that food seeds should not be patented. I realize that's a way of life of the last 30 years under globalization. But with many changes in the world today including in your scarcity map, which was very interesting, of water scarcity that included part of Siberia and China and Asia, there are many paradigm shifts. There's a whole nuclear power resurgence in China, India and Russia, South Korea. So we could be thinking outside the box in this way. Would you address a rollback in the patenting in terms of changing regulations, especially since there's a fracas now of fighting between Monsanto and Dupont and others. Thank you.

F: I doubt it. I think the intellectual property protection is not likely to be rolled back. I'd also remind you that protection of life forms really did come from plants, from the Plant Variety Protection Act of 1970. And that really was the basis on which the first bacterial patents were issued. That train has left the station, and frankly it is really what allows companies to produce what they do and invest in the research that they do. I think we would lose more than we would gain. In fact I was just in India last week. We were having this discussion, and there was a recognition. They are very ambivalent because they have a great dedication to the public sector. But the public sector in this particular case is not terribly efficient.

REPORTER: Hello. I'm wondering if you looked into the crops quinoa which is I believe drought-tolerant.

F: Yes.

REPORTER: And salicornia which is saline-tolerant.

F: Actually, the last slide I showed is one that I got from the Seawater Foundation, and they really have developed salicornia. In fact it's one of the major—that's a point I didn't make—it's one of the major hopeful crops for biofuels. It really does make a high quality oil. There's a lot of reading to do. There's some molecular biology to do. But I think that, together with mangroves as carbon sinks and inland waterways could really make a huge difference in the most arid parts of the world.

REPORTER: I didn't hear you address the role of hydroponics and particularly if hydroponics can play a role in future commodity crops like wheat, corn, etcetera. Is there any movement in that direction since it's a great water saver and land saver?

F: Actually the second to last slide was an integrated hydroponics, called aquaponics, hydroponics, fish aquaculture combined with raising of mostly vegetable crops. That was a slide from the Virgin Islands experimental station. And it's done quite a lot in the Negave as well because this is very water conservative. One major technical issue to address, however, is the feed. At the moment, aquaculture feed for fish is often wild caught. How do we develop a feed that is part of the whole system? That's a research topic.

[Applause]